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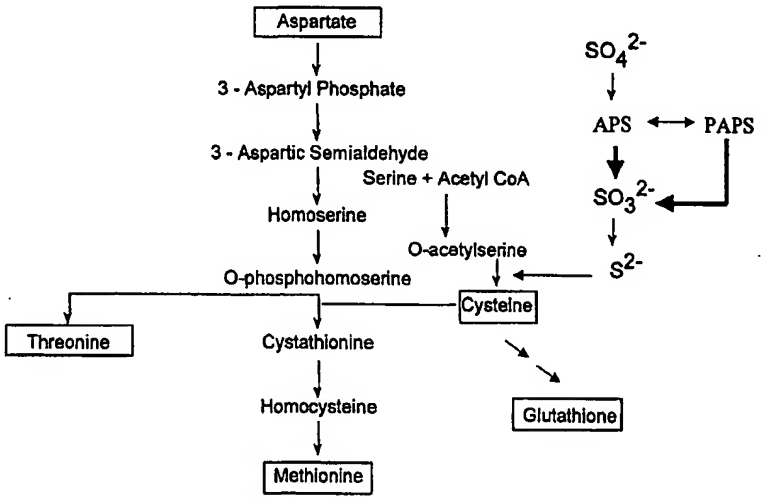

(57) Abstract

Methods for modulating levels of at least one organic sulfur compund in plants are provided. Also provided are plants, plant seeds, and plant cells produced by the methods. The methods comprise stably transforming a plant with a DNA construct encoding a (P)APS reductase enzyme capable of altering the level of at least one organic sulfur compound. Also provided are methods for reducing oxidative stress in plants and for increasing the nutritional quality of plants and seeds.

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METHODS FOR MODULATING THE LEVELS OF ORGANIC SULFUR COMPOUNDS IN PLANTS

FIELD OF THE INVENTION

The invention relates to the genetic manipulation of plants, particularly to altering sulfur metabolism in plants and plant seeds.

BACKGROUND OF THE INVENTION

Sulfur in its reduced form plays an important role in plant metabolism, being involved in the biosynthesis of a wide range of primary and secondary S-containing metabolites. In plants, sulfur metabolism includes the uptake of sulfate from the environment, assimilation into organic compounds, and channeling into proteins and secondary substances.

Plants and microorganisms are able to reduce sulfate to sulfide for synthesis of the thiol group of cysteine. Sulfate is first activated by ATP sulfurylase, forming 5'-adenylylsulfate (APS). APS can be phosphorylated by APS kinase, forming 3'-phosphoadenosine-5'-phosphosulfate (PAPS). Either APS or PAPS can be used for sulfate reduction. Generally, prokaryotes and fungi use PAPS, whereas photosynthetic eukaryotes use APS.

Cysteine, methionine, and sulfur-containing vitamins such as biotin or thiamine are essential in human nutrition. Sulfur-mediated functions include electron transport in Fe/S-clusters, structural and regulatory roles via protein disulfide bridges, and catalytic centers. Additionally, secondary sulfur compounds include signaling molecules, anti-carcinogens and atmospheric compounds. See Hell (1997) *Planta 202*:138.

Often plant protein is deficient in the sulfur amino acids, especially methionine, as well as other essential amino acids such as lysine and tryptophan. As a result, diets must be supplemented with these amino acids in order to provide a balanced diet. A goal of plant breeding has been to increase the amount of sulfur amino acids present in the seed.

A number of methods have been described for increasing sulfur amino acid content of plants. Generally, these methods provide for the overexpression of a high methionine seed storage protein. The method entails overexpressing the seed storage protein in a transformed plant. Previously, methods for increasing the sulfur amino acid content of crops were attempted through breeding. However, these methods have met with limited success. There is therefore a need for methods of producing significant levels of the sulfur amino acids in plants and plant seeds.

Aerobic organisms are vulnerable to damage from reactive oxygen species. This is a particular problem for plants because reactive oxygen species are generated as a byproduct of oxygenic photosynthesis and carbon dioxide fixation. It would therefore be desirable to provide a method for reducing oxidative stress in plants and for increasing the nutritional quality of plants and seeds.

SUMMARY OF THE INVENTION

An object of the present invention is to provide methods for increasing the nutritional value of plants.

Another object of the present invention is to provide plants and plant parts having increased nutritional value.

Another object of the present invention is to provide plants and plant parts having increased levels of organic sulfur compounds.

Another object of the present invention is to provide plants and plant parts having increased levels of methionine.

Another object of the present invention is to provide a method for decreasing oxidative stress in plants.

In accordance with the present invention, methods for modulating the level of at least one organic sulfur compound in plants are provided. Also provided are plants, plant tissues, plant seeds and plant cells produced by the methods. The methods comprise stably transforming a plant with a DNA construct encoding a (P)APS reductase enzyme. (P)APS reductase is defined as an enzyme that is capable of reducing sulfur in the form of APS or PAPS to produce sulfite. The (P)APS reductase enzyme has an activity such that, the transformed plant exhibits

altered levels of at least one organic sulfur compound. Also provided is a method for reducing oxidative stress in plants.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 sets forth the biosynthesis for the organic sulfur compounds cysteine and methionine with the proposed modifications of the invention.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the subject invention, compositions and methods for modulating the biosynthesis of organic sulfur compounds in plants, particularly sulfur amino acids, more particularly cysteine and methionine are provided. The methods involve transforming a plant with one or more nucleic acid(s) encoding a (P)APS reductase enzyme capable of modulating the biosynthesis of at least one organic sulfur compound. The plant may also comprise one or more additional nucleic acid(s) selected from nucleic acids encoding enzymes involved in amino acid biosynthesis and sulfate reduction (Figure 1).

By "organic sulfur compounds" is intended compounds such as glutathione, phytochelatins, sulfur-containing vitamins, glucosinolates, dimethylsulfoniopropionate and amino acids such as methionine and cysteine.

APS reductase catalyzes a key reaction in the sulfate assimilation pathway of higher plants leading to the synthesis of cysteine and the antioxidant compound glutathione. *In vitro* biochemical studies revealed that the enzyme is activated by oxidation. Exposure of plants to ozone induces a rapid increase in APS reductase activity that coincides with the accumulation of cysteine and glutathione. These results indicate that redox regulation of APS reductase may provide a mechanism for rapid response to oxidative stress.

Glutathione is a tripeptide composed of the amino acids glutamate, cysteine and glycine. Glutathione exists in the reduced form and in the oxidized form which together form a biological redox buffer that is predominantly in a reduced state.

Sulfate reduction occurs in both roots and shoots of plants. Most of the sulfur transported in the xylem to the leaves is in non-reduced SO_4^{2-}. Some

transport back to roots and other parts of the plant occurs through phloem, and both free SO_4^{2-} and organic sulfur compounds are transported. In leaves, the process of sulfate reduction occurs in chloroplasts. In roots, most or all of the process occurs in proplastids.

The first step of sulfate assimilation in all cells is reaction of SO_4^{2-} with ATP producing adenosine-5'-phosphosulfate (APS) and pyrophosphate. This step is catalyzed by ATP sulfurylase. In plants the sulfur of APS is further reduced by (P)APS reductase activity. This enzyme is markedly stimulated during oxidative stress and is a key enzyme in sulfate assimilation in plants. Under oxidative stress, the enzyme is stimulated about 40-fold. This change in activity appears to be related to a conformational change in the enzyme in response to a change in the redox status of the chloroplast.

Therefore, a preferred embodiment of the present invention is to provide (P)APS reductase expression, which is relatively active under reducing conditions, such as in the chloroplast. Other methods can be used for increasing the activity of the (P)APS reductase enzyme, such as protein engineering or DNA shuffling.

Glutathione biosynthesis is also activated under oxidative stress, as a mechanism to mitigate the effects of the stress. Thus, under conditions of oxidative stress, sulfate reduction is enhanced through the increased activity of (P)APS reductase enzyme. The flow of the resulting reduced inorganic sulfur is directed toward glutathione biosynthesis via cysteine by increased activity of glutathione biosynthetic enzymes.

ATP sulfurylase, the first enzyme in sulfate reduction, is relatively unresponsive to oxidative stress. Therefore, this enzyme does not represent a significant limiting factor in sulfate reduction, when sulfate itself is not limiting. Thus, as shown in Figure 1, by supplying the chloroplast with a (P)APS reductase enzyme, which is metabolically active under reducing conditions, sulfate reduction and subsequently the production of organic sulfur compounds can be increased in the plant.

Other nucleic acids encoding enzymes involved in sulfate reduction or organic sulfur compound biosynthesis, such as cysteine and methionine biosynthesis, can be utilized to shunt the pathway in particular directions. For

example, APS kinase can be utilized to shunt APS into PAPS, leading to additional substrate for (P)APS reductase enzyme. In the same manner, cystathionine gamma synthase can be utilized to direct the flow of cysteine toward methionine.

Also, antisense constructs for any of the enzymes can be utilized to direct biosynthesis into a particular product or to stop biosynthesis for the build-up of a particular compound. For example, an antisense construct for gamma glutamylsynthetase (gs) can be used to shunt reduced sulfur into methionine production from cysteine even under oxidative conditions.

Yeast and bacterial (P)APS reductase enzymes are relatively active under reducing conditions, whereas higher plant (P)APS reductase enzyme is relatively inactive under these conditions. Thus, the expression of bacteria or yeast or a modified (P)APS reductase enzyme in the chloroplast, which maintains a relatively reducing environment under normal conditions, is one method for enhancing sulfate reduction. In this manner, the metabolic pathway of interest can be manipulated for the high production of sulfur-containing amino acids or other downstream organic sulfur compounds.

As noted above, the pathway can also be manipulated to decrease levels of a particular compound by transformation of antisense DNA sequences that prevent the conversion of the precursor compound into the particular compound being regulated. This method can be useful for "shunting" reduced sulfur from one pathway to another.

Any means for producing a plant comprising the (P)APS reductase nucleic acid or both the (P)APS reductase nucleic acid and at least a second nucleic acid are encompassed by the present invention. For example, the second (or additional) nucleic acid(s) of interest can be used to transform a plant at the same time as the (P)APS reductase nucleic acid (cotransformation). The second nucleic acid can also be introduced into a plant that has already been transformed with the (P)APS reductase nucleic acid. Alternatively, transformed plants, one expressing the (P)APS reductase enzyme and one expressing the second nucleic acid, can be crossed to bring the nucleic acids together in the same plant. Subsequent crosses or transformations can bring additional sequences together in the plant.

Enzymes involved in cysteine and methionine biosynthesis are known in the art. See, for example, aspartokinase (Masakazu *et al.* (1992) "Mutant Aspartokinase Gene," Japan Patent 1994062866-A 1 08-MAR-1994, Accession No. E06825; Omori *et al.* (1993) *J. Bacteriol. 175(3)*:785-794; Accession No. X60821; Moriya *et al.* (1995) Japan Patent 1997070291-A 13 18-MAR-1997; Accession No. E12770); aspartate semialdehyde dehydrogenase (Calzada, F.R.A., Direct Submission, Centro Nacional de Investigaciones Cientificas, Avenida 25 esq. 158 reparto Cubanacan, Playa Ciudad de la Habana, Codigo Postal 6990, CUBA (1997), Accession No. Y15281; Daniel *et al.* (1993) *J. Mol. Biol. 232 (2)*:468-483; Accession No. Z22554; Chen *et al.* (1993) *J. Biol. Chem.*; Accession No. Z22554; Accession No. U90239; Brakhage *et al.* (1990) *Biochimie 72(10)*:725-734; Accession No. Z75208; Gothel *et al.* (1997) *Eur. J. Biochem. 244 (1)*:59-65; Accession No. Z75208); homoserine kinase (See number two under aspartokinase, Accession No. X60821; Nakabachi *et al.* (1997) *Insect Biochem. Mol. Biol. 27*:1057-1062; Accession No. AB004856; Ryoichi *et al.* (1986) Japan Patent 1987232392-A 1 12-OCT-1987 (JP1986076298); Accession No. E01358; Sadao *et al.* Japan Patent 1993207886-A 4 20-AUG-1993; Accession No. D14072); threonine synthase (see number two under aspartokinase, Accession No. X6082; Accession No. Z46263; Rognes, S.E., Direct Submission, October 24, 1994, to University of Oslo, Department of Biology, Blindern, 0316 Norway, Accession No. Z46263; Accession No. L41666; Clepet *et al.* (1992) *Mol. Microbiol. 6(21)*:3109-3119; Accession No. X65033 S50569; Cami, B., Direct Submission, March 11, 1992, Laboratoire de Chimie Bacterienne, Centre Nationale de la Recherche, Scientifique, 31 Chemin I. Aiguier, BP 71 13277 Marseille Cedex, FRANCE, Accession No. X65033 S50569); cystathionine gamma synthase (cgs) (Kim and Leustek (1996) "Cloning and analysis of the gene for cystathionine gamma-synthase from *Arabidopsis thaliana*," Plant Mol. Biol. 32 (6), 1117-1124, USA, Accession No. AF069317; Locke *et al.*, Direct Submission, June 3, 1997, AG Biotechnology, Dupont AF Products, PO Box 80402, Wilmington, DE 19880-0402 USA, Accession No. AF007786); cystathionine beta lyase (Bork *et al.* (1997) *Plant Physiol. 115*:864-864; Accession No. AJ001148; Sienko, M., Direct Submission, June 5, 1995, Marzena Sienko, Genetics, Institute of Biochemistry

and Biophysics, Pawinskiego 5a, Warsaw 02-106, POLAND, Accession No. U28383; Ravanel *et al.* (1995) *Plant Mol. Biol. 29 (4)*:875-882; Accession No. L40511); methionine synthase (Kurvari *et al.* (1995) *Plant Mol. Biol. 29*:1235-1252; Accession No. U36197; Ravanel *et al.* (1998) *Proc. Natl. Acad. Sci. USA 95(13)*:7805-7812; Accession No. U97200; Michalowski *et al.*, Direct Submission, January 12, 1997, Biochemistry, University of Arizona, BioSciences West 513, Tucson, AZ 85721 USA, Accession No. U84889; Eichel *et al.* (1995) *Eur. J. Biochem. 230 (3)*:1053-1058; Accession No. X83499); ATP sulfurylase (Murillo *et al.* (1995) *Arch. Biochem. Biophys. 323(1)*:195-204; Accession No. U06275; Leustek *et al.* (1994) *Plant Physiol. 105*:897-902; Accession No. U05218; Bolchi *et al.*, Direct Submission, July 28, 1997, Scienze Biochimiche, Viale delle Scienze, Parma, PR 43100 ITALY, Accession No. AF016305; Laue *et al.* (1994) *J. Bacteriol. 176*:3723-3729; Accession No. L26897; Laeremans *et al.* Accession No. AJ001223); APS kinase (apk) (Korch *et al.* (1991) *Mol. Gen. Genet. 229(1)*:96-108; Accession No. S55315; Arz *et al.* (1994) *Biochim. Biophys. Acta 1218 (3)*:447-452; Accession No. AF044285; Schiffmann *et al.* "Isolation of cDNA clones encoding adenosine-5'-phophosulfate-kinase (EC2.7.1.25) from *Catharanthus roseus* (Accession No. AF044285) and an isoform (akn2) from *Arabidopsis* (Accession No. AF043351)(PGR98-116)," *Plant Physiol. 117 (3)*:1125 (1998); Accession No. AF044285; Jain *et al.* (1994) *Plant Physiol. 105*:771-772; Accession No. U05238; Lee *et al.* (1998) *Biochem. Biophys. Res. Commun. 247*:171-175; Accession No. U05238); APS reductase (Speich *et al.* (1994) *Microbiology 140 (Pt6)*:1273-1284; Accession No. Z69372; Setya *et al.* (1996) *Proc. Natl. Acad. Sci. USA 93(23)*:13383-1338; Accession No. U56921; Bick *et al.* (1998) *Proc. Natl. Acad. Sci. USA 95(14)*:8404-8409; Accession No. U56921); PAPS reductase (Krone *et al.* (1991) *Mol. Gen. Genet. 225(2)*:314-319; Accession No. Y07525; Krone *et al.* (1990) *FEBS Lett. 260 (1)*:6-9; Accession No. Y07525; Gutierrez-Marcos *et al.* (1996) *Proc. Natl. Acad. Sci. USA 93*:13377-13382; Accession No. U53865; Schwenn, J.D., Direct Submission, July 2, 1993, Ruhr-University-Bochum, Fac. Biology, Biochemistry of Plants, Universitaetsstr. 150, D44780 Bochum, GERMANY, Accession No. Z23169; see number five under ATP sulfurylase, Accession No. AJ001223; Bussey *et al.* (1997) *Nature 387*

(6632 Suppl.):103-105; Accession No. U25840 U00094); sulfite reductase (Accession No. Y07525; Accession No. Z23169; Hipp *et al.* (1997) *Microbiology 143 (Pt 9)*:2891-2902; Accession No. U84760; Pott *et al.* (1998) *Microbiology 144 (Pt 7)*:1881-1894; Accession No. U84760; Bork *et al.* (1998) *Gene 212 (1)*:147-153; Accession No. Y10157; Mbeguie-A-Mbeguie *et al.* Accession No. AF071890; Bruehl *et al.* (1996) *Biochim. Biophys. Acta 1295*:119-124; Accession No. Z49217; Hummerjohann *et al.* (1998) *Microbiology 144 (Pt 5)*:1375-1386; Accession No. AF026066; serine acetyltransferase (Accession No. X80938; Accession No. D88529; Saito *et al.* (1995) *J. Biol. Chem. 270 (27)*:16321-16326; Accession No. D49535); cysteine synthase (Hesse *et al.* (1998) "Isolation of cDNAs encoding cytosolic (Accession No. AF044172) and plastidic (Accession No. AF044173) cysteine synthase isoforms from *Solanum tuberosum* (PGR98-057)," *Plant Physiol. 116*:1604, Accession No. AF044173; Brander *et al.* (1995) *Plant Physiol. 108*:1748-1748; Accession No. X85803; Topczewski *et al.* (1997) *Curr. Genet. 31 (4)*:348-356; Accession No. U19395); gamma glutamylcysteine synthase (Powles *et al.* (1996) *Microbiology 142 (Pt 9)*:2543-2548; Accession No. U81808 L75931; Accession No. AL031018; EU *Arabidopsis* sequencing project, Direct Submission, July 3, 1998, at the Max-Planck-Institut fuer Biochemie, Am Klopferspitz 18a, D-82152 Martinsried, FRG, Accession No. AL031018); glutathione synthetase (Okumura *et al.* (1997) *Microbiology 143 (Pt 9)*:2883-2890; Accession No. D88540; Inoue *et al.* (1998) *Biochim. Biophys. Acta 1395 (3)*:315-320; Accession No. Y13804; Accession No. Y10984; Accession No. U22359).

Variants and functional fragments, including shufflents, of the above enzymes or of P(APS) reductase may also be utilized. It is only required that the enzymes have an activity sufficient to modulate the level of a particular organic sulfur compound in a plant. Variants can be produced by methods known in the art. Variant proteins include those proteins derived from the native protein by deletion (so-called truncation), addition, or substitution of one or more amino acids at one or more sites in the native protein.

For example, amino acid sequence variants of the polypeptide can be prepared by mutations in the cloned DNA sequence encoding the native protein of interest. Methods for mutagenesis and nucleotide sequence alterations are well

known in the art. See, for example, Walker and Gaastra, eds. (1983) *Techniques in Molecular Biology* (MacMillan Publishing Company, New York); Kunkel (1985) *Proc. Natl. Acad. Sci. USA* 82:488-492; Kunkel *et al.* (1987) *Methods Enzymol.* 154:367-382; Sambrook *et al.* (1989) *Molecular Cloning: A Laboratory Manual* (2d ed., Cold Spring Harbor Laboratory Press, Plainview, New York); U.S. Patent No. 4,873,192; and the references cited therein; herein incorporated by reference. Guidance as to appropriate amino acid substitutions that do not affect biological activity of the protein of interest may be found in the model of Dayhoff *et al.* (1978) *Atlas of Protein Sequence and Structure* (Natl. Biomed. Res. Found., Washington, D.C.), herein incorporated by reference. Conservative substitutions, such as exchanging one amino acid with another having similar properties, may be preferred.

The (P)APS reductase nucleic acids, as well as any additional genes of interest can be optimized for enhanced expression in plants of interest. See, for example, EPA0359472; WO91/16432; Perlak *et al.* (1991) *Proc. Natl. Acad. Sci. USA* 88:3324-3328; and Murray *et al.* (1989) *Nucleic Acids Res.* 17:477-498. In this manner, the nucleic acids can be synthesized utilizing plant-preferred codons. See, for example, Murray *et al.* (1989) *Nucleic Acids Res.* 17:477-498, the disclosure of which is incorporated herein by reference. In this manner, synthetic nucleic acids can also be made based on the distribution of codons a particular host uses for a particular amino acid.

Another method for obtaining modified enzymes that can alter the level of at least one organic sulfur compound is by sequence shuffling. Sequence shuffling is described in PCT publication No. 96/19256. See also, Zhang *et al.* (1997) *Proc. Natl. Acad. Sci. USA* 94:4504-4509. Libraries of recombinant polynucleotides are generated from a population of related sequence polynucleotides comprising sequence regions that have substantial sequence identity and can be homologously recombined *in vitro* or *in vivo*.

In some instances, the enzymes of interest are natively expressed in the plant. However, by transformation with heterologous promoters, expression levels or patterns can be altered. See, for example, Sambrook *et al.* (1989) *Molecular Cloning: A Laboratory Manual* (2d ed., Cold Spring Harbor Laboratory Press,

Plainview, New York). and Innis *et al.* (1990) *PCR Protocols: A Guide to Methods and Applications* (Academic Press, New York).

In a preferred embodiment, the nucleic acids of interest are targeted to the chloroplast for expression. In this manner, where the nucleic acid of interest is not directly inserted into the chloroplast, the expression cassette will additionally contain a nucleic acid encoding a transit peptide to direct the nucleic acid of interest to the chloroplasts. Such transit peptides are known in the art. See, for example, Von Heijne *et al.* (1991) *Plant Mol. Biol. Rep. 9*:104-126; Clark *et al.* (1989) *J. Biol. Chem. 264*:17544-17550; Della-Cioppa *et al.* (1987) *Plant Physiol. 84*:965-968; Romer *et al.* (1993) *Biochem. Biophys. Res. Commun. 196*:1414-1421; and, Shah *et al.* (1986) *Science 233*:478-481.

Chloroplast targeting sequences are known in the art and include the chloroplast small subunit of ribulose-1,5-bisphosphate carboxylase (Rubisco), (de Castro Silva Filho *et al.* (1996) *Plant Mol. Biol. 30*:769-780; Schnell *et al.* (1991) *J. Biol. Chem. 266(5)*:3335-3342); 5-(enolpyruvyl)shikimate-3-phosphate synthase (EPSPS) (Archer *et al.* (1990) *J. Bioenerg. Biomemb. 22(6)*:789-810); tryptophan synthase (Zhao *et al.* (1995) *J.Biol. Chem. 270(11)*:6081-6087); plastocyanin (Lawrence *et al.* (1997) *J. Biol. Chem. 272(33)*:20357-20363); chorismate synthase (Schmidt *et al.* (1993) *J. Biol. Chem. 268(36)*:27477-27457); and the light harvesting chlorophyll a/b binding protein (LHBP) (Lamppa *et al.* (1988) *J. Biol. Chem. 263*:14996-14999). See also Von Heijne *et al.* (1991) *Plant Mol. Biol. Rep. 9*:104-126; Clark *et al.* (1989) *J. Biol. Chem. 264*:17544-17550; della-Cioppa *et al.* (1987) *Plant Physiol. 84*:965-968; Romer *et al.* (1993) *Biochem. Biophys. Res Commun. 196*:1414-1421; and Shah *et al.* (1986) *Science 233*:478-481.

Methods for transformation of chloroplasts are known in the art. See, for example, Svab *et al.* (1990) *Proc. Natl. Acad. Sci. USA 87*:8526-8530; Svab and Maliga (1993) *Proc. Natl. Acad. Sci. USA 90*:913-917; Svab and Maliga (1993) *Embo J. 12*:601-606. The method relies on particle gun delivery of DNA containing a selectable marker and targeting of the DNA to the plastid genome through homologous recombination. Additionally, plastid transformation can be accomplished by transactivation of a silent plastid-borne transgene by tissue-specific expression of a nuclear-encoded and plastid-directed RNA polymerase.

Such a system has been reported in McBride *et al.* (1994) *Proc. Natl. Acad. Sci. USA 91*:7301-7305.

The nucleic acids can be combined with constitutive, tissue-specific, or chloroplast promoters for expression the metabolite of interest. Such constitutive promoters include, for example, the core promoter of the Rsyn7 (copending U.S. Patent Application Serial No. 08/661,601), the core CaMV 35S promoter (Odell *et al.* (1985) *Nature 313*:810-812); rice actin (McElroy *et al.* (1990) *Plant Cell 2*:163-171); ubiquitin (Christensen *et al.* (1989) *Plant Mol. Biol. 12*:619-632 and Christensen *et al.* (1992) *Plant Mol. Biol. 18*:675-689); pEMU (Last *et al.* (1991) *Theor. Appl. Genet. 81*:581-588); MAS (Velten *et al.* (1984) *EMBO J. 3*:2723-2730); ALS promoter (U.S. Patent Application Serial No. 08/409,297), and the like. Other constitutive promoters include, for example, U.S. Patent Nos. 5,608,149; 5,608,144; 5,604,121; 5,569,597; 5,466,785; 5,399,680; 5,268,463; and 5,608,142.

"Seed-specific" promoters of the invention include embryo-specific promoters. Additionally, such promoters include globulin 1, cruciferin, napin, B-conglycinin, phaseolin, as well as other promoters associated with storage proteins or involved in fatty acid biosynthesis.

Expression cassettes will comprise a transcriptional initiation region linked to the coding sequence or antisense sequence of the nucleotide of interest. Such an expression cassette is generally provided with a plurality of restriction sites for insertion of the sequence to be under the transcriptional regulation of the regulatory regions. The expression cassette may additionally contain selectable marker genes.

The transcriptional initiation region, the promoter, may be native or analogous or foreign or heterologous to the plant host. Additionally, the promoter may be a synthetic sequence. By foreign is intended that the transcriptional initiation region is not found in the native plant into which the transcriptional initiation region is introduced.

The transcriptional cassette will include in the 5'-to-3' direction of transcription, a transcriptional and translational initiation region, a DNA sequence of interest, and a transcriptional and translational termination region functional in

plants. The termination region may be native with the transcriptional initiation region, may be native with the DNA sequence of interest, or may be derived from another source. Convenient termination regions are available from the Ti-plasmid of *A. tumefaciens*, such as the octopine synthase and nopaline synthase termination regions. See also Guerineau *et al.* (1991) *Mol. Gen. Genet. 262*:141-144; Proudfoot (1991) *Cell 64*:671-674; Sanfacon *et al.* (1991) *Genes Dev. 5*:141-149; Mogen *et al.* (1990) *Plant Cell. 2*:1261-1272; Munroe *et al.* (1990) *Gene 91*:151-158; Ballas *et al.* (1989) *Nucleic Acids Res. 17*:7891-7903; Joshi *et al.* (1987) *Nucleic Acids Res. 15*:9627-9639.

In preparing the expression cassette, the various DNA fragments may be manipulated, so as to provide for the DNA sequences in the proper orientation and, as appropriate, in the proper reading frame. Toward this end, adapters or linkers may be employed to join the DNA fragments or other manipulations may be involved to provide for convenient restriction sites, removal of superfluous DNA, removal of restriction sites, or the like. For this purpose, *in vitro* mutagenesis, primer repair, restriction, annealing, resubstitutions, *e.g.*, transitions and transversions, may be involved.

Transformation protocols as well as protocols for introducing nucleotide sequences into plants may vary depending on the type of plant or plant cell, *i.e.* monocot or dicot, targeted for transformation. Suitable methods of introducing nucleotide sequences into plant cells and subsequent insertion into the plant genome include microinjection (Crossway *et al.* (1986) *Biotechniques 4*:320-334), electroporation (Riggs *et al.* (1986) *Proc. Natl. Acad. Sci. USA 83*:5602-5606, *Agrobacterium*-mediated transformation (Townsend *et al.*, U.S. Pat No. 5,563,055); direct gene transfer (Paszkowski *et al.* (1984) *EMBO J. 3*:2717-2722), and ballistic particle acceleration (see, for example, Sanford *et al.*, U.S. Patent No. 4,945,050; Tomes *et al.* (1995) "Direct DNA Transfer into Intact Plant Cells via Microprojectile Bombardment," in *Plant Cell, Tissue, and Organ Culture: Fundamental Methods*, ed. Gamborg and Phillips (Springer-Verlag, Berlin); and McCabe *et al.* (1988) *Biotechnology 6*:923-926). Also see Weissinger *et al.* (1988) *Annual Rev. Genet. 22*:421-477; Sanford *et al.* (1987) *Particulate Science and Technology 5*:27-37 (onion); Christou *et al.* (1988) *Plant Physiol. 87*:671-674

(soybean); McCabe *et al.* (1988) *Bio/Technology 6*:923-926 (soybean); Finer and McMullen (1991) *In Vitro Cell Dev. Biol.* 27P:175-182 (soybean); Singh *et al.* (1998) *Theor. Appl. Genet.* 96:319-324 (soybean); Datta *et al.* (1990) *Biotechnology 8*:736-740 (rice); Klein *et al.* (1988) *Proc. Natl. Acad. Sci. USA 85*:4305-4309 (maize); Klein *et al.* (1988) *Biotechnology 6*:559-563 (maize); Tomes, U.S. Patent No. 5,240,855; Buising *et al.*, U.S. Patent Nos. 5,322,783 and 5,324,646; Tomes *et al.* (1995) "Direct DNA Transfer into Intact Plant Cells via Microprojectile Bombardment," in *Plant Cell, Tissue, and Organ Culture: Fundamental Methods*, ed. Gamborg (Springer-Verlag, Berlin) (maize); Klein *et al.* (1988) *Plant Physiol. 91*:440-444 (maize); Fromm *et al.* (1990) *Biotechnology 8*:833-839 (maize); Hooykaas-Van Slogteren and Hooykaas (1984) *Nature (London) 311*:763-764; Bytebier *et al.* (1987) *Proc. Natl. Acad. Sci. USA 84*:5345-5349 (Liliaceae); De Wet *et al.* (1985) in *The Experimental Manipulation of Ovule Tissues,* ed. Chapman *et al.* (Longman, New York), pp. 197-209 (pollen); Kaeppler *et al.* (1990) *Plant Cell Reports 9*:415-418; and Kaeppler *et al.* (1992) *Theor. Appl. Genet. 84*:560-566 (whisker-mediated transformation); D'Halluin *et al.* (1992) *Plant Cell 4*:1495-1505 (electroporation); Li *et al.* (1993) *Plant Cell Reports 12*:250-255 and Christou and Ford (1995) *Annals of Botany 75*:407-413 (rice); Osjoda *et al.* (1996) *Nature Biotechnology 14*:745-750 (maize via *Agrobacterium tumefaciens*); all of which are herein incorporated by reference.

The biosynthesis of organic sulfur compounds can be altered in any plant of interest. Of particular interest are plants useful for human and domestic animal food. Such plants include forages and seed crop plants such as cereal crops and oil seed crops. Of particular interest are plants where the seed is produced in high amounts, or the seed or a seed part is edible. Seeds of interest include the oil seeds, such as seeds from *Brassica*, cotton, soybean, safflower, sunflower, coconut, palm, etc.; grain seeds such as wheat, barley, rice, corn, etc.; other seeds including oats, pumpkin, squash, poppy, sesame, peanut, peas, beans, cocoa, coffee, etc.; and tree nuts such as walnuts, pecans, almonds, etc. Especially preferred plants are corn, soybean, sunflower, *Brassica*, wheat, barley, rye, rice, millet, sorghum, safflower, potato, pea, and alfalfa.

The modified plant may be grown into plants in accordance with conventional ways. See, for example, McCormick *et al.* (1986) *Plant Cell. Reports* 5:81-84. These plants may then be grown, and either pollinated with the same transformed strain or different strains, and the resulting hybrid having the desired phenotypic characteristic identified. Two or more generations may be grown to ensure that the subject phenotypic characteristic is stably maintained and inherited and then seeds harvested to ensure the desired phenotype or other property has been achieved.

The following examples are offered by way of illustration and not by way of limitation.

EXAMPLES

Example 1: Transformation and Regeneration of Maize Callus

Immature maize embryos from greenhouse donor plants are bombarded with a plasmid containing a (P)APS reductase nucleic acid operably linked to the ubiquitin promoter plus a plasmid containing the selectable marker gene PAT (Wohlleben *et al.* (1988) *Gene* 70:25-37) that confers resistance to the herbicide Bialaphos. Transformation is performed as follows.

The ears are surface sterilized in 30% Clorox bleach plus 0.5% Micro detergent for 20 minutes, and then rinsed two times with sterile water. The immature embryos are excised and placed embryo axis side down (scutellum side up), 25 embryos per plate, on 560 Y medium for 4 hours and then aligned within the 2.5-cm target zone in preparation for bombardment.

A plasmid vector comprising a (P)APS reductase nucleic acid operably linked to the ubiquitin promoter is constructed. This plasmid DNA plus plasmid DNA containing a PAT selectable marker is precipitated onto 1.1 μm (average diameter) tungsten pellets using a $CaCl_2$ precipitation procedure as follows: 100 μl prepared tungsten particles in water, 10 μl (1 μg) DNA in TrisEDTA buffer (1 μg total), 100 μl 2.5 M $CaCl_2$ and 10 μl 0.1 M spermidine.

Each reagent is added sequentially to the tungsten particle suspension, while maintained on the multitube vortexer. The final mixture is sonicated briefly and allowed to incubate under constant vortexing for 10 minutes. After the precipitation period, the tubes are centrifuged briefly, liquid removed, washed with

500 ml 100% ethanol, and centrifuged for 30 seconds. Again the liquid is removed, and 105 µl 100% ethanol is added to the final tungsten particle pellet. For particle gun bombardment, the tungsten/DNA particles are briefly sonicated and 10 µl spotted onto the center of each macrocarrier and allowed to dry about 2 minutes before bombardment.

The sample plates are bombarded at level #4 in particle gun #HE34-1 or #HE34-2. All samples receive a single shot at 650 PSI, with a total of ten aliquots taken from each tube of prepared particles/DNA.

Following bombardment, the embryos are kept on 560Y medium, an N6 based medium, for 2 days, then transferred to 560R selection medium, an N6 based medium containing 3 mg/liter Bialaphos, and subcultured every 2 weeks. After approximately 10 weeks of selection, selection-resistant callus clones are sampled for PCR and activity of the nucleic acid of interest. Positive lines are transferred to 288J medium, an N6 based medium with lower sucrose and hormone levels, to initiate plant regeneration. Following somatic embryo maturation (2-4 weeks), well-developed somatic embryos are transferred to medium for germination and transferred to the lighted culture room. Approximately 7-10 days later, developing plantlets are transferred to medium in tubes for 7-10 days until plantlets are well established. Plants are then transferred to inserts in flats (equivalent to 2.5" pot) containing potting soil and grown for 1 week in a growth chamber, subsequently grown an additional 1-2 weeks in the greenhouse, then transferred to classic 600 pots (1.6 gallon) and grown to maturity. Plants are monitored for expression of the (P)APS nucleic acid and methionine.

All publications and patent applications mentioned in the specification are indicative of the level of those skilled in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious that certain changes and modifications may be practiced within the scope of the appended claims.

THAT WHICH IS CLAIMED:

1. A method for modulating biosynthesis of at least one organic sulfur compound in plants, the method comprising stably transforming the plant with a DNA construct comprising a nucleic acid encoding a (P)APS reductase enzyme, wherein the nucleic acid is operably linked to a promoter that drives expression in a plant and wherein the level of the at least one organic sulfur compound is altered.

2. The method of claim 1, wherein the construct further comprises a chloroplast transit peptide.

3. The method of claim 1, wherein the (P)APS reductase enzyme is a yeast (P)APS reductase enzyme.

4. The method of claim 1, wherein the (P)APS reductase enzyme is a bacterial (P)APS reductase enzyme.

5. The method of claim 1, further comprising transforming the plant with at least a second DNA construct comprising at least a second nucleic acid encoding an enzyme functional in the biosynthesis of a selected organic sulfur compound, wherein the at least second nucleic acid is operably linked to a promoter that drives expression in a plant.

6. The method of claim 5, wherein the second construct comprises a chloroplast transit peptide.

7. The method of claim 5, wherein the second nucleic acid encodes the enzyme cgs or the enzyme apk.

8. The method of claim 7, wherein the second nucleic acid encodes the enzyme cgs.

9. The method of claim 8, wherein said plant comprises a third DNA construct comprising a third nucleic acid encoding an enzyme functional in the biosynthesis of a selected organic sulfur compound, wherein said third nucleic acid encodes the enzyme apk.

10. The method of claim 1, wherein the organic sulfur compound is an amino acid or glutathione.

11. The method of claim 10, wherein the amino acid is cysteine or methionine.

12. A plant having increased levels of at least one organic sulfur compound, the plant having stably transformed into its genome a DNA construct comprising a nucleic acid encoding a (P)APS reductase enzyme, wherein the nucleic acid is operably linked to a promoter that drives expression in a plant.

13. The plant of claim 12, wherein the construct further comprises a chloroplast transit peptide.

14. The plant of claim 12, wherein the (P)APS reductase enzyme is a yeast PAPS reductase enzyme.

15. The plant of claim 12, wherein the (P)APS reductase enzyme is a bacterial PAPS reductase enzyme.

16. The plant of claim 12, further comprising at least a second DNA construct comprising at least a second nucleic acid encoding an enzyme functional in the biosynthesis of a selected organic sulfur compound, wherein the at least second nucleic acid is operably linked to a promoter that drives expression in a plant.

17. The plant of claim 16, wherein the second construct further comprises a chloroplast transit peptide.

18. The plant of claim 16, wherein the second nucleic acid encodes the enzyme cgs or the enzyme apk.

19. The plant of claim 12, wherein the organic sulfur compound is an amino acid or glutathione.

20. The plant of claim 19, wherein the amino acid is cysteine or methionine.

21. The plant of claim 12, wherein the plant is a monocot.

22. The plant of claim 21, wherein said monocot is selected from the group consisting of maize, wheat, barley, rye, rice, millet, and sorghum.

23. The plant of claim 12, wherein the plant is a dicot.

24. The plant of claim 23, wherein said dicot is selected from the group consisting of soybean, sunflower, *Brassica*, and alfalfa.

25. Seed of the plant of claim 12.

26. A plant cell having increased levels of at least one organic sulfur compound, the plant cell having stably transformed into its genome a DNA construct comprising a nucleic acid encoding a (P)APS reductase enzyme, wherein the nucleic acid is operably linked to a promoter that drives expression in a plant cell.

27. The plant cell of claim 26, wherein the construct further comprises a chloroplast transit peptide.

28. The plant cell of claim 26, wherein the (P)APS reductase enzyme is a yeast PAPS reductase enzyme.

29. The plant cell of claim 26, wherein the (P)APS reductase enzyme is a bacterial (P)APS reductase enzyme.

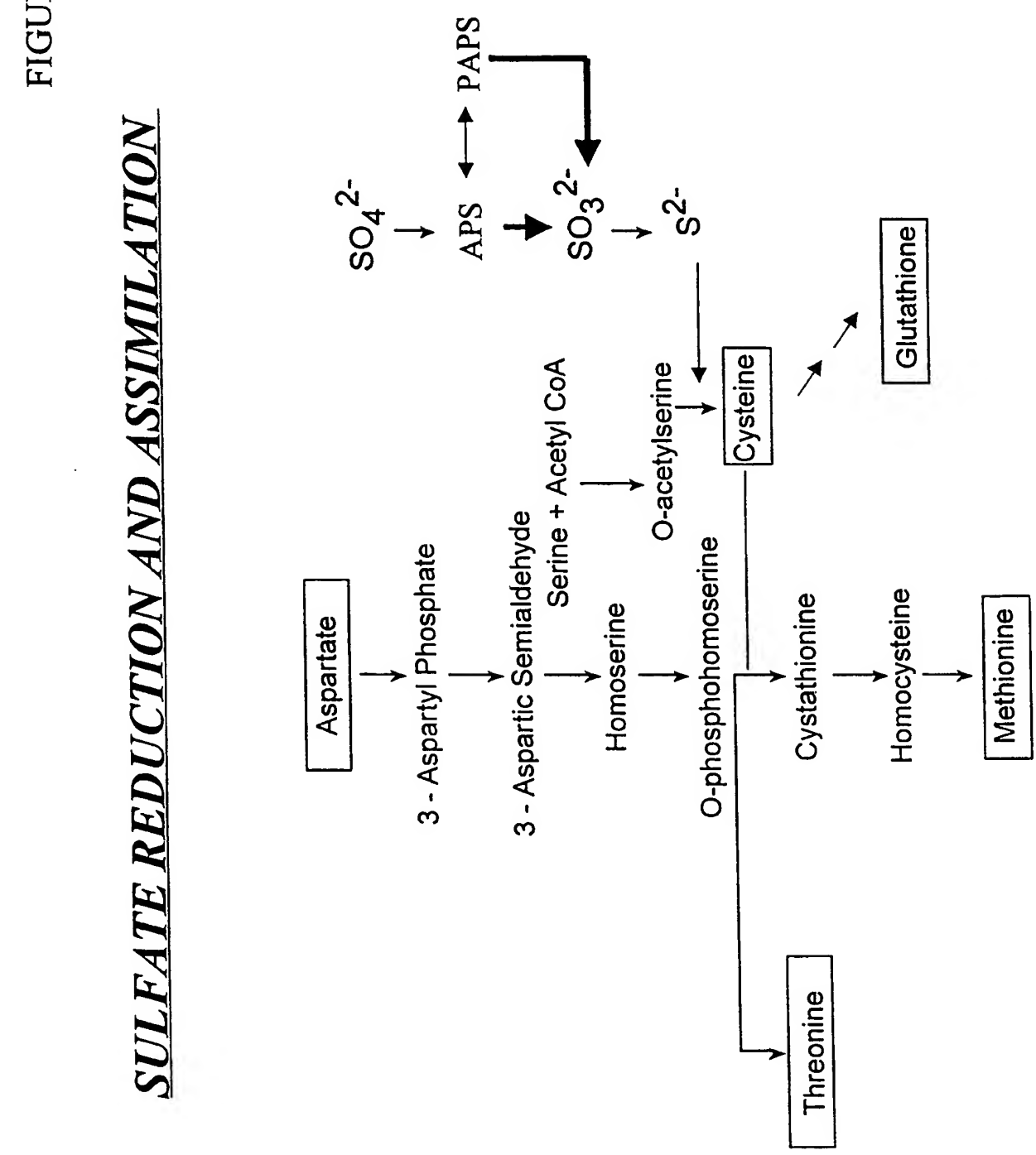
30. The plant cell of claim 26, further comprising at least a second DNA construct stably transformed into the genome of the plant, wherein the at least second DNA construct comprises at least a second nucleic acid encoding an enzyme functional in the biosynthesis of a selected organic sulfur compound and wherein the at least second nucleic acid is operably linked to a promoter that drives expression in a plant cell.

31. The plant cell of claim 30, wherein the second construct further comprises a chloroplast transit peptide.

32. The plant cell of claim 30, wherein the at least second nucleic acid encodes the enzyme cgs or the enzyme apk.

33. A method for decreasing oxidative stress in plants comprising stably transforming the plant with a DNA construct comprising a nucleic acid encoding a (P)APS reductase enzyme, wherein the nucleic acid is operably linked to a promoter that drives expression in a plant.

FIGURE 1


SULFATE REDUCTION AND ASSIMILATION
SO_4^{2-}
APS
PAPS
SO_3^{2-}
S^{2-}
Aspartate
3 - Aspartyl Phosphate
3 - Aspartic Semialdehyde
Serine + Acetyl CoA
Homoserine
O-acetylserine
O-phosphohomoserine
Cysteine
Glutathione
Cystathionine
Homocysteine
Methionine
Threonine

INTERNATIONAL SEARCH REPORT

Internal Application No
PCT/US 00/04381

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C12N15/82 C12N15/52 C12N9/02 A01H5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C12N A01H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
BIOSIS, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BICK J A ET AL: "PLANT SULFUR METABOLISM - THE REDUCTION OF SULFATE TO SULFITE" CURRENT OPINION IN PLANT BIOLOGY,GB,QUADRANT SUBSCRIPTION SERVICES, vol. 1, no. 3, June 1998 (1998-06), pages 240-244-244, XP000853523 ISSN: 1369-5266 the whole document ---	
A	HELL R: "MOLECULAR PHYSIOLOGY OF PLANT SULFUR METABOLISM" PLANTA,DE,SPRINGER VERLAG, vol. 202, no. 202, 1997, pages 138-148-148, XP000856032 ISSN: 0032-0935 the whole document --- -/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 July 2000	01/08/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Holtorf, S

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INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/US 00/04381

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BRUNOLD C ET AL: "III. REGULATION OF SULFUR METABOLISM IN PLANTS: FIRST MOLECULAR APPROACHES" PROGRESS IN BOTANY - FORTSCHRITTE DER BOTANIK,DE,SPRINGER, BERLIN, vol. 58, no. 58, 1997, pages 164-186-186, XP000856058 ISSN: 0340-4773 the whole document ---	
A	GUTIERREZ-MARCOS ET AL: "three members of a novel small gene-family from Arabidopsis able to complement functionally an Escherichia coli mutant defective in PAPS reductase activity encode proteins with thioredoxin-like domain and APS reductase activity" PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF USA,US,NATIONAL ACADEMY OF SCIENCE. WASHINGTON, vol. 93, no. 93, November 1996 (1996-11), pages 13377-13382-13382, XP002122426 ISSN: 0027-8424 cited in the application ---	
A	LEE ET AL: "APS kinase from Arabidopsis thaliana: genomic organization, expression, and kinetic analysis of the recombinant protein" BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS,US,ACADEMIC PRESS INC. ORLANDO, FL, vol. 247, no. 247, 9 June 1998 (1998-06-09), pages 171-175-175, XP002122480 ISSN: 0006-291X the whole document ---	
A	JAIN ET AL: "a cDNA clone for 5'-adenylylphosphosulfate kinase from Arabidopsis thaliana" PLANT PHYSIOLOGY,US,AMERICAN SOCIETY OF PLANT PHYSIOLOGISTS, ROCKVILLE, MD, vol. 105, no. 105, 1994, pages 771-772-772, XP002122478 ISSN: 0032-0889 the whole document ---	

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INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/US 00/04381

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	KORCH C ET AL: "CLONING NUCLEOTIDE SEQUENCE AND REGULATION OF MET14 THE GENE ENCODING THE APS KINASE OF SACCHAROMYCES-CEREVISIAE" MOLECULAR & GENERAL GENETICS, vol. 229, no. 1, 1991, pages 96-108, XP002142801 ISSN: 0026-8925 cited in the application the whole document ---	
A	KIM JUNGSUP ET AL: "Cloning and analysis of the gene for cystathionine gamma-synthase from Arabidopsis thaliana." PLANT MOLECULAR BIOLOGY, vol. 32, no. 6, 1996, pages 1117-1124, XP002142802 ISSN: 0167-4412 cited in the application the whole document ---	
P,X	WO 00 04161 A (DU PONT ;ALLEN STEPHEN M (US); FALCO SAVERIO CARL (US)) 27 January 2000 (2000-01-27) the whole document ---	1,12, 21-26
T	SUTER,M., ET AL. : "ADENOSINE 5'-PHOSPHOSULFATE SULFOTRANSFERASE AND ADENOSINE 5'-PHOSPHOSULFATE REDUCTASE ARE IDENTICAL ENZYMES" THE JOURNAL OF BIOLOGICAL CHEMISTRY, vol. 275, no. 2, 14 January 2000 (2000-01-14), pages 930-936, XP002142803 the whole document -----	

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Interna al Application No
PCT/US 00/04381

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0004161 A	27-01-2000	AU 4990099 A	07-02-2000
		AU 5099099 A	07-02-2000
		AU 5099199 A	07-02-2000
		AU 5100299 A	07-02-2000
		AU 5211999 A	07-02-2000
		WO 0004165 A	27-01-2000
		WO 0004154 A	27-01-2000
		WO 0004162 A	27-01-2000
		WO 0004167 A	27-01-2000